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CONTROLLED NUCLEAR FUSION AND HIGH-TEMPERATURE PLASMA PHYSICS RESEARCH IN USSR

L.A. Artsimovich

§ 1. The final goal of controlled nuclear fusion research is the development of methods permitting deuterium and tritium be used as new nuclear fuels for energy production. Exceedingly high temperatures are the necessary conditions that intensive fusion reactions in deuterium or its mixture with tritium take place. The temperature required should be of an order of hundreds millions degrees. In this region of temperatures the nuclear fuel is fully ionized plasma. Besides very high temperatures a plasma must also be of a concentration high enough as the reaction yield is proportional to the square of concentration.

As far back as the idea of the controlled nuclear fusion arose it became clear that the main task to be solved is to provide a very perfect thermal insulation of the nuclear fuel. High vacuum is the only medium that the hot plasma can be in contact without instantaneous losing the heat energy accumulated in it. To insulate, however, a bunch of hot plasma in vacuum the plasma pressure must be counterbalanced by some equilibrium force on its boundary. Such a force can be produced by a magnetic field if the magnetic lines of force of that field surround the plasma region. The magnetic field serves here as an elastic sheat of which the pressure balances the kinetic gas pressure of the plasma tending to expand.

It should be remarked, however, that the magnetic thermal insulation is far from perfect and the energy leaks outward even through a very strong magnetic field. A possible measure of the thermal insulation quality is the time while a temperature of the plasma in a magnetic field remains sufficiently high. To find a characteristic time τ the total thermal energy of all the particles available in plasma should be divided by the energy flux transfered by fast neutrals escaping from the plasma per unit time. The parameter τ can be also considered as a mean lifetime of a fast particle in plasma. It is obvious that a thermonuclear reactor of net energy gain is possible to construct only after some method has been found to cofine fast particles in plasma for a sufficient period of time. All the rather long history of the controlled nuclear research is in fact a struggle for a longer τ.

Research on controlled nuclear fusion has been going on in different countries for about fifteen years. Some results obtained in controlled nuclear fusion research were for the first time presented for the international scientific forum at the Second United Nations Conference on the Peaceful Uses of Atomic Energy in 1958.

The initial stage of the research falling on the years when the work was carried out in different countries independently from one another was reviewed there. A considerable predominance of theoretical analysis over experimental investigations was characteristic for that time. The status of experimental research did not correspond that time to the complicity of the task. During the years following the conference when a number of great difficulties was everywhere encountered in practice it was gradually understood that the experimental technics must be improved far more. It also became clear that technical aspects of the problems associated with controlled nuclear fusion are possible to discuss only if an experimental foundation is layed down for the high temperature plasma physics.

The present paper is a review of the recent development of the high temperature plasma physics research in

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the USSR. These cover a large number of various approaches. Of them the major ones are:

1. Investigation of plasma properties in what is called open magnetic traps, i.e. magnetic systems where plasma is confined in the region with a magnetic field with unclosed lines of force. 2. Studies of heating a plasma by a current passing through it in toroidal systems with a very strong stabilizing magnetic field. 3. Studies of the plasma behaviour in strong high-frequency electromagnetic field (plasma confinement and heating).

§ 2. Let us see first the investigations on plasma properties in magnetic traps with open ends. The plasma confinement in such systems is based on one law of the motion of charged particles in a magnetic field. A particle that moves along a line of force towards the region of the increasing magnetic field undergoes slowing-down. If the angle between the direction of its velocity and the line of force is rather large the particle approaching the regiom of a stronger field will experience a reflection as if from a mirror. If therefore the magnetic field strength increased in both directions from some central region the plasma particles could be confined inside a limited space between the "magnetic mirrors". The simpliest magnetic system of the type under question is a conventional trap with two magnetic mirrors shown schematically in Fig.1. The magnetic field of that configuration could be produced by two coils in which the currents would be in the same direction. Note that in the trap with two mirrors a field strength H increases with the distance from the centre along the lines of force but also decreases in radial directions. If the direction of the current would change in one of the coils it would resemble a magnetic trap with magnetic fields opposing each other given in Fig.2. The magnetic

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field strength in such a trap increases with the distance from the central region in all directions. At some point of this region H drops down to zero. A great interest has lately been payed to magnetic traps with more complex field geometries ("hybride type" fields). These magnetic systems will be discussed below.

First the attention of experimenters was mostly payed to the simpliest type of traps with two magnetic mirrors. The first experimental device with magnetic mirrors was put into action at the Kurchatov Atomic Energy Institute (AEI) in Moscow in 1957. A plasma at high ion temperature was built up in this device by the method of "ion magnetron", i.e the ions were extracted from a cold plasma arc produced along the axis of the magnetic system and accelerated by applying a short high-voltage pulse.

After applying the voltage the plasma arc sprays and the space between the magnetic mirrors would thus be filled with a high temperature plasma of a concentration= $10^9 - 10^{10} cm^{-3}$. The net energy of plasma ions after switching off the high voltage makes 1.5 - 2 kev that corresponds to a temperature of the order of $2.10^{7o}K$. The main aim of experiments have been carried out for a number of years with the device which has been called the "ion magnetron" (IM) was to study the properties of a plasma captured in a magnetic field after switching off the high voltage. First of all it was needed that a containment time of the created plasma bunch, i.e. a lifetime τ of fast ions in the trap be determined. To do it one should measure how a plasma concentration (i.e. a number of fast ions per cubic centimeter) varies in time. The scope of the present paper do not permit us to discuss here the technique of these measurements and we shall therefore report the experimental results only.

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The treatment of the experimental data collected in three year work with IM enabled to make a basic conclusion as follows: a plasma bunch having an initial concentration of particles from $\sim 10^8$ to $\sim 10^{10}$ and an average ion energy of approximately 1.5 kev is unstable and decays during the time not longer that several hundred microseconds. Instability indications are clearly seen in oscillograms obtained with the help of diagnostic equipment used for measuring plasma parameters. The oscilloscope traces are traversed with numerous high frequency oscillations.

These results were the first concincing confirmation for theoretical predictions on plasma instability in fields of this geometry characteristic of simple traps with magnetic mirrors. The theoretical analysis has shown that due to the decrease of the magnetic field strength along the radius a number of deformations having a shape of repeated peaks and wells on the surface of the plasma bunch may appear and develop. Such a wrinkled structure has been called a "flute deformation" and the reason causing it has been called a convective instability. It is the convective instability that took place in the experiments done with the IM device. It follows in particular from the analysis of observed plasma density fluctuations.

In 1958 when the experiments with IM were at an early stage the construction of a large device with magnetic mirrors was completed in the Kurchatov Atomic Energy Institute. This device called "Ogra" is intended for studying a possibility of producing a high temperature plasma by injecting fast ions from outside. The fast molecular ions of hydrogen injected into a trap are dissociated by collisions with residual gas atoms or with particles

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of a cold plasma produced within the trap volume. The dissociation results in production of protons that in the magnetic field follow a curved path having half the radius of curvature of the molecular ion path. This irreversible change of the trajectory leads to trapping atomic ions between two magnetic mirrors. At an initial stage of experiments carried out with OGRA the simpliest method of building up protons having an energy of 80 kev by the dissociation of ions H_2^+ on residual gas was studied. The concentration of fast ions built up in a chamber depended on the intensity of a current injected as well as a number of other factors but it remained very low at all times. With the injector being on it usually made $10^7 cm^{-3}$ (in a volume of about 10 m^3).

After the efficiency of the initial method for building up a plasma was found inadequate it has been decided to try a dissociation of molecular ions in passing through a dense arc discharge (this method was formerly applied with DCX in the USA). A method for producing an intense lithium arc has been developed in the Scientific and Research Vacuum Institute. A long arc dischare column of a fully ionized cold plasma having a concentration of $3.10^{12} cm^{-3}$ is established in vacuum along the lines of force through all the length of the magnetic trap. The ionized column may serve as an effective means for dissociating a beam of hydrogen ions passing through it. The experiments on building up fast protons with the use of the lithium arc in OGRA were initiated in 1963. Correlating to initial assumptions the dissociation efficiency was found high enough. The method made possible the average concentration of protons in OGRA to increase up to $5.10^8 cm^{-3}$. It has also been discovered that the dense lithium arc column piercing a hydrogen plasma acts

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as a factor stabilizing plasma instabilities. Until the lithium arc operates the oscillations characteristic of a flute instability development do not appear in the plasma. The lifetime of protons extends up to 15 milliseconds. A perspective of employing this phenomenon in practice to stabilize "thermonuclear" plasma instabilities appears doubtful for a dence column of lithium arc if present in a hot plasma would absorb the thermal energy of fast particles. On the other hand, however, the stabilizing effect of the arc column on a surrounding rarefied plasma with fast ions has a certain heuristic value as an indication that the search for new methods of suppressing plasma instabilities in the simpliest systems with magnetic mirrors is not hopeless.

§ 3. The negative results of experiments aimed at producing a high temperature plasma having high density in the mirror machines have convinced a number of Soviet physicists as far back as in 1960 that the task can be solved quicker if using magnetic systems with fields of different geometry where the main obstacle, i.e. the convective type instability can be eliminated. The simpliest magnetic system that should theoretically satisfy the above requirement is a system with opposing fields shown in Fig.2 with lines of force of a hyperbolic shape. In a field of this geometry a field strength H increases in all directions from the middle region. In accordance with the basic principles of the theory one may therefore expect a plasma trapped within the region of a weak field between the coils be stable at least with respect to flute deformations. The theory unfortunately predicts another substantial defect for systems with opposing fields. A high density plasma trapped in such a system should entirely push the magnetic

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field aside from the region surrounding the point in the space where an initial value H is equal to zero. However, the plasma cannot be confined in the region of zero field for a long time as charged particles would leave that region of space after several reflections from its boundaries. It seems, therefore, difficult to hope the magnetic trap of this class be suitable for confining a high temperature dense plasma for a long time.

It is long before that the point of view has been expressed in the USSR that a sufficient thermal insulation can be provided for a high temperature plasma only im systems with hybride magnetic fields comprizing the properties of the simple systems given in Fig.1 and 2 but having no their basic drawbacks. In such magnetic systems the magnetic field strength should increase in all directions outside from the plasma boundaries. However a field strength H should not drop to zero in the region filled with the plasma. One of the natural ways of realizing a magnetic system satisfying both of the above conditions and ensuring therefore a priori a plasma stability is schematically presented in Fig.3. The magnetic field is produced by coils and rectilinear current-carrying conductors disposed symmetrically around the common axis of the coils. The coils form a conventional field with two magnetic mirrors along the axis. A current being opposit in each two neighboring rectilinear conductors produces a magnetic field of which the configuration is given in Fig.4. The superposition of the both magnetic fields leads to the increase of a resultant vector H in all directions from the middle region to be filled with a plasma. The experiments with such a hybride magnetic configuration were performed for the first time in the Kurchatov Atomic Energy Institute in 1961, where the device IM with 6 longitudinal current-

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carrying conductors mounted inside its chamber were used for this purpose. The above mentioned method of magnetron acceleration was applied for filling a trap with a high temperature plasma. Even in the early experiments carried out under vacuum conditions not yeat perfect the plasma lifetime increased several times when the field produced by rectilinear conducters was switched on and high frequency oscillations disappeared in oscillograms of the process. To move onward it was necessary that the vacuum conditions be improved. For this a new device PR-5 with longitudinal current conductors placed outside the wacuum volume (see Fig.3) was built in 1962. The experiments with PR-5 were undertaken in 1963. Initially the magnetron ion acceleration was also used to produce a plasma in these experiments. By this method it was possible to build up a plasma of a concentration of 10^9-10^{10} cm^{-3} and of an average ion energy of 4 kev (temperature $\sim$ 40 millions degrees).

The basic results obtained in the described experiments are presented if Fig. 5 and 6. The first figure shows a time variation of plasma concentration when plasma is trapped in a magnetic field at good vacuum conditions. For comparison the same figure shows an oscilloscope trace of plasma decay when the current in the rectilinear conductors is switched off and the field is produced by the main coils only. The average lifetime in the case of the hybride field makes about 50 milliseconds at a vacuum of the order of 1.10^{-8} mm Hg. In a conventional mirror machine with the same field strength this time dies not exceed 250 microseconds. In Fig.6 one can see the dependence of a plasma confinement time in a hybride field a residual pressure of neutral gas p_v. It makes us sure that $1/\tau$ is proportional to p_v. From here it follows that the only process resulting in fast ion escaping from a trap is that of fast ion charge exchange

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on neutral atoms. The stated data indicate that under the conditions in question plasma remains in a stable equilibrium state. The same has been proved by the shape of oscilloscope traces displaying a variation in plasma parameters. There is no high frequancy oscillations on the oscilloscope traces. The significance of these experiments lies in the fact that the possibility of a prolonged stable confinement of such a plasma (with fast ions) in a magnetic field has been proved for the first time during all the history of studying high temperature plasmas. The extension of the obtained information over the region of higher concentrations naturally constitutes the greatest interest. In accordance with the theoretical predictions a new type of instability may occur at higher concentrations due to growing of plasma oscillations at frequencies close to the iom gyrofrequency in a magnetic field. To check up if the instability exists the concentration should be increased at least by a factor of 10, i.e. up to 10^{10}- 10^{11} cm^{-3}. We have already got the results of experiments carried out with the device PR-5 in this direction. For a new series of measurements another method different from that mentioned above was used to fill a trap. An original electrostatic instability that may occur in a bunch of cold plasma is in use for the new method. At some parameters of the discharge that creates a columm passing along the axis of the magnetic system the high frequency electric fields appear in the discharge and accelerate ions. The average ion energy is 1-2 kev. In experiments on building up a high temperature plasma from an unstable plasma column the average concentration of particles could be brought up to $\sim 3.10^{10} cm^{-3}$: This concentration is about an order of magnitude higher than that could be usually obtained by the magnetron method of building plasma up. It has been shown from the experiments

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that at the mentioned concentration the instability indications are absent as formally although we remark that the plasma decay followed by a flux of a neutral charge-exchange particles is not any more exponentional in time.

Another device with a hybride field was decided to construct to expand the utilization of the possibilities of these fields. A plasma was assumed to build up in the device by ionizing a beam of fast atoms injected from outside. This device, named OGRA-II, repeats the configuration of the magnetic field in PR-5, but exceeds it considerably in size and in H. A strength of the field produced by the coils in the middle part of the trap can be brought up to 15,000 gauss at the field strength in the mirror region of 23,000 gauss. The inner diameter of the vacuum chamber is 70 cm. The construction of OGRA-II was completed in may 1964, its picture is given in Fig.7.

§ 4. Investigation of the ohmic heating of plasma in quazistationary discharges provided a plasma circular column is in a strong longitudinal magnetic field represents a traditional trend in the Kurchatov Atomic Energy Institute. The strength of the longitudinal magnetic field stabilizing the plasma column is many times higher than that produced by the plasma current. That is the principle difference between the experiments described and the experiments implemented with the use of devices analogous to the known device "ZETA". With the devices of the "TOKAMAK" family (see Fig.8) experiments have already been carried out for a number of years. The toroidal chamber with a plasma column created inside it is put on the core of an iron transformer. The plasma current is initiated under the influence of a voltage induced in the chamber. To provide for better vacuum the chamber is made two-sheathed. The inside chamber (liner) is made of thin stainless steel.

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A diaphragm limiting the plasma column cross section is fitted inside the liner so that to reduce interaction between the plasma and the liner surface. The liner is isolated from the outside sheath made of thick copper that serves for maintaining the circular plasma current column in equilibrium state by means of eddy currents. A whole family of TOKAMAKS has been so far constructed; of this family of devices the largest one T-3 is presented in Fig.9; it was put into operation in 1962.

The theoretical analysis of the plasma column behaviour indicates that it may undergo a rough instability. This instability occurs if the self-magnetic field of the current to the longitudinal stabilizing field ratio is wrong. To get a stable plasma the longitudinal field strength H to a self-magnetic field of the current ratio should exceed the $\frac{R}{r}$ ratio at least several times, where R is the ring radius, r is the radius of the column cross section.

At the early stage of experiments with the first models of the TOKAMAK devices the longitudinal field strength did not exceed several thousand gauss; to provide therefore for that stability we had to limit strongly the plasma current. Due to that the amount of energy released in the discharge was also limited and it was impossible to heat the plasma up to higher temperatures. However, even at a high H_o we could not first get smooth oscilloscope traces and observed a fast decay of particle concentration during the discharge. They tried to attribute it to uncertain instability mechanisms that caused a very fast "anomalous" diffusion of plasma across magnetic lines of force. This point of view predominated until it was found that the phenomenon ascribed to the "anomalous" diffusion could be explained as a motion of the

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plasma loop inside the chamber due to the disturbance of its equilibrium state. Small displacements of the loop effect strongly the plasma properties because of its interaction with the diaphragm. The plasma turn may move inside the vacuum chamber under the influence of different causes. Even a very small component of the external magnetic field perpendicular to the direction of the plasma current may displace the turn for a noticeable distance. A change in plasma pressure due to heating and current redistribution over the plasma loop cross section may be other causes of plasma motion. A vigorous effect of small displacements of the plasma ring on the discharge process has been proved experimentally. That is why a special correction for a magnetic field is in use to compensate the influence of factors affecting the plasma equilibrium conditions. It led to a considerable change in the process picture. The conditions of the discharge obtained with the T-3 device are characteristic of a long confinement time and a high conductivity of plasma (see Fig.10 with some results of the measurements). The plasma conductivity increases with the increase of H_0. It reaches 3.10^{16} CGSE at H_0= 25,000 gauss and a plasma concentration $n \sim 10^{13} cm^{-3}$. It corresponds to a plasma electron temperature of about 2.10^{6} °K. Note that in such a way they have obtained a plasma loop with a conductivity like that with a metal. Under such conditions of the discharge the oscilloscope traces become smooth and the measurements do not reveal a fast decay of n till the plasma current remains high. So it can be concluded that in circular systems with a strong field the plasma heating can be performed together with maintaining its stability.

§ 5. A significant place in investigations on high temperature plasma physics in the USSR has been occupied by research devoted to studying interaction between plas-

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mas and high-frequency fields. The following are the two main purposes in the research: a/ to clear up if the plasma can be confined and stabilized with the help of high-frequency fields; b/ to develop methods of fast heating a plasma. The development of various means of confining and stabilizing plasmas with the help of high-frequency fields is carried on in the Kurchatov Atomic Energy Institute and in Radiotechnical Institute in Moscow, in Scientific and Research Institute for Electrical and Physical Apparatus in Leningrad and in Physical and Technical Institute in Sukhumi. Experimental research on methods for producing high temperature plasma where the main function of confinement is laid upon high-frequency fields have not yet brought positive results. Studying of combined systems advanced far more. In combined systems an insulated plasma formation is maintained at equilibrium state by means of stationary and slowly changing magnetic fields and high-frequency fields serve as a stabilizing factor. The method of high-frequency stabilization of a plasma column with a high longitudinal current is studied in the Kurchatov Atomic Energy Institute. A stabilising arrangement is a system of rods placed symmetrically around the discharge chamber and in parallels with the plasma column (Fig.11). Currents produced by a high-frequency generator flow through the each two rods in opposite directions and thanks to that the high-frequency fields are induced. At high enough amplitude and frequency the fields can provide the plasma column stability with respect to the most dangerous kink deformations. Experiments prove the existence of the stabilizing effect.

The method of plasma dynamic stabilization is studied in Sukhumi. In this case the stabilizing system consists also of rods placed symmetrically relative to the axis of the magnetic trap. A high-frequency current passes through

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them and produces a rotating magnetic field. Besides, direct currents flowing through the each two rods in opposite directions produce a stationary field of a geometry analogous to that of the rotating one. The combined effect of the high-frequency and the stationary fields is equivalent to the effect of two fields rotating in opposite directions. As follows from experiments the development of flute deformations characteristic of traps with magnetic mirrors is suppressed in this system. However, it should be pointed out that in the experiments carried out so far the plasma temperature was very low. It is therefore difficult to evaluate the perspectives of using the described method for the high frequency stabilization (it also concerns experiments studying the effect of high frequency-fields on a plasma column with current).

The affect of super high frequency of decimetric waves electromagnetic fields on plasma is also being investigated. The experiments with a super high-frequency field affecting plasma in a stationary longitudinal magnetic field have been carried out in the Kurchatov Atomic Energy Institute. The super high frequency field produced an additional radial pressure. In such a system a convective instability of plasma may appear to be suppressed (or to be strongly attenuated).

§ 6. Methods of high frequency heating a plasma are rapidly developed in the Soviet Union. A number of fruitful theoretical ideas have recently been suggested in this field. They have successfully being realized in practice. Different resonance phenomena resulting in particle acceleration ban be used for heating a plasma. For example, an alternating electromagnetic field of a rather small amplitude and a frequency close to the angular velocity of rotation (Larmor frequency) of ions affects a plasma in

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a strong stationary magnetic field, then a resonance acceleration may occur. This is what we call a cyclotron resonance method that may be used for heating the ion component of the plasma. The above mentioned method is being developed in Physical and Technical Institute in Kharkov for a number of years. The results obtained thus far should be recognized promising. The ion component of the plasma enclosed in a mirror machine was heated by the cyclotron resonance up to the temperature of 15 million degrees with the use of high frequency generators of a comparatively low power. The concentration of the plasma then made $\sim 12.10^{13} cm^{-3}$.

A new trend in plasma heating methods have lately arisen in the USSR. It proceeds in general from the idea that in a plasma any ordered motion of high enough intensity is not stable and should dissipate into small-scale oscillations that convert quickly its energy into the energy of thermal motion. Theoretical research carried out in the Kurchatov Atomic Energy Institute and the Novosibirsk Nuclear Physics Institute have defined this general idea more concretely that resulted in a new method suggested for heating plasma by a steep front pulse of high-frequency field. If a short high-frequency pulse with amplitude $H_1 \sim H_0$ where H_0 is a uniform stationary (or slowly changing) field inside a cylindrical chamber affects a cold plasma bunch a strong shock wave develops and propagates in the plasma radially inward to the axis (the both fields are parallel to one another). The jump in the magnetic field strength of this wave is caused by the fact that there appears an azimuthal electron current. At a very fast rate of rise of the alternating field the kinetic energy of the directional azimuthal motion of electrons reaches a great value. This motion is not stable

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and its energy should therefore convert into the thermal energy of the plasma electron component. The new method of heating a plasma by pulse high-frequency fields is named "turbulent" heating. Experimental studies of the method are developed at the Kurchatov Atomic Energy Institute and Nuclear Physics Institute in Novosibirsk. In the experiments being carried out at the Kurchatov Atomic Energy Institute the alternative field of the frequency of about 10 MHz is produced by discharging a condenser bank of a very low self-inductance across a one-turn coil wrapped around a chamber filled preliminary with a cold plasma. A stationary field strength H_0 makes 500 to 2 or 3 thousand gauss. Duration of a fast-damping pulse of the high-frequency fields makes several tenths of a microsecond.

Experiments show that an alternative field pulse sharply increases the energy of plasma electrons. At a concentration of about $10^{12} cm^{-3}$ the average energy of plasma electrons is brought up to 1000-1500 ev in some microseconds after the alternative field damped completely. If the strength of the main field does not remain constant and increases then after a high-frequency pulse the plasma undergoes compression and the energy of electrons increases again. This is the way how the plasma with an electron temperature of about 10^8 degrees and a concentration of $10^{13} cm^{-3}$ can be produced. A method for producing pulse fields of an even higher rate of rise and a higher amplitude has been developed in Novosibirsk. It has enabled to realize the turbulent heating of the plasma ion component. The ion energy brought up was ~ 10 kev. Thus judging from the results obtained on the first stage of developing the method of turbulent heating is very promising.

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§ 7. Besides the basic trends mentioned above wide-scale experiments are being carried out in the Soviet Union in a number of other branches of the high temperature plasma physics. The present paper cannot describe the purposes and the results of these numerous investigations and we have to limit ourselves to irrelevant problems only. Research on plasma injectors, on interaction between plasma jets and magnetic fields as well as on methods of injecting plasma into magnetic traps are developed in a wide scale at Physical and Technical Institute in Kharkov, at the Kurchatov Atomic Energy Institute and in Physical Institute of the Academy of Sciences of the USSR. Investigation on powerful pulse discharges of a very short duration is going on at the Kurchatov Atomic Energy Institute, at Physical and Technical Institute in Sukhumi and at the Moscow State University of which the aim is to clear up the cause of the appearence of fast particles in plasma in such processes. The basic lows of plasma diffusion in a magnetic field are studied at Physical and Technical Institutes in Leningrad and Sukhumi and at Nuclear Physics Institute in Novosibirsk. A relativistic plasma is studied at Nuclear Physics Institute in Novosibirsk. Great attention is also being payed to developing various experimental technics for measuring the main parameters characteristic of plasma behaviour. The paper so far spoke almost only about experimental studies. It does not, however, mean that in the Soviet Union they do not pay necessary attention to developing theoretical aspects of the plasma physics. Our experimental program is in fact mutually connected with the theory research. Theoretical investigations initiate the basic trends in experiments. Any significant result obtained from experiments immediately becomes a subject of theoretical analysis. Theoretical

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research carried out in our country on the problem of stability has a great principle significance for the high temperature plasma physics as a whole. A number of mechanisms causing instabilities in nonhomogeneous plasma were for the first time investigated in the Soviet Union. Since plasma is always unstable near boundaries the above mentioned investigations have a direct practical significance. Theoretical studies of processes occurring in turbulent plasmas, i.e. in plasmas with a grown instability, have played an important role in developing physical notions of the plasma properties. These studies enable to estimate a possible rate of diffusion and heat transfer in unstable plasma. It is unfortunate that here we have to confine ourselves to these general remarks since the purpose and the size of the paper do not allow us to deep in the plasma theory. In conclusion we must come back once again to the problem of controlled fusion and to try to formulate in brief its present state and its probable future.

The development of this problem can be compared with climbing up a stair with very high steps. The height of each of them can be measured after have climbed it up. By the time of the Second Geneva Conference we had a great stock of ideas, but in practice we were able to produce a plasma with temperatures of about one million degrees confined for several seconds only. It was the first step of the controlled fusion stair. The stable long-term confinement of a plasma in hybride magnetic fields, the efficient ohmic heating carried out in stabilized systems as well as the successful development of the new method of the plasma "turbulent" heating represent the second step. The next (but not the last) one will be reached when a stable high temperature plasma is produced with such a high density that it could serve as a powerful neutron source

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excelling accelerating devices in efficiency. The term "controlled thermonuclear fusion" will actually acquire a real meaning at that stage only.

We hope by the Fourth Geneva Conference the climbing up to the third step of the thermonuclear stair will be completed.

CAPTIONS

Fig.1. Magnetic field geometry in the magnetic trap with open ends.

Fig.2. Magnetic field geometry in the magnetic trap with opposing fields.

Fig.3 Disposition of the current-carrying conductors in the trap with a hybride field geometry

Fig.4 Magnetic field geometry in the hybride magnetic trap

Fig.5 Oscilloscope traces of plasma decay in the PR-5 device. The top curve shows the case of having the stabilizing field on; the bottom curve shows the case of having the stabilizing field off.

Fig.6. Reverse lifetime of plasma as a function of neutral hydrogen pressure:

1. The stablizing field being off
2. The stabilizing field being on

Fig. 7. General view of the OGRA-II device

Fig.8. Oscillogram of the loop voltage, of the plasma current and of the microwave interferometer signal (the TOKOMAK-3 device)

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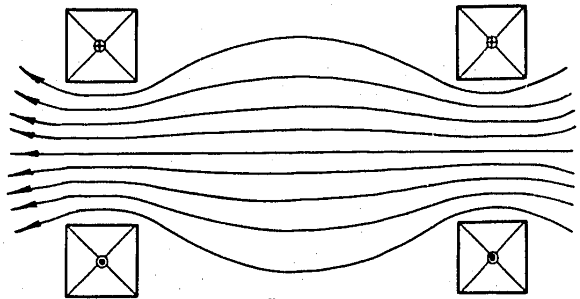

Fig. 1

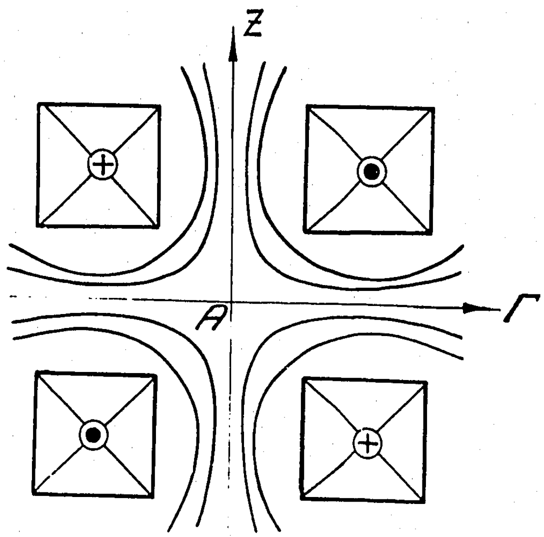

Fig. 2

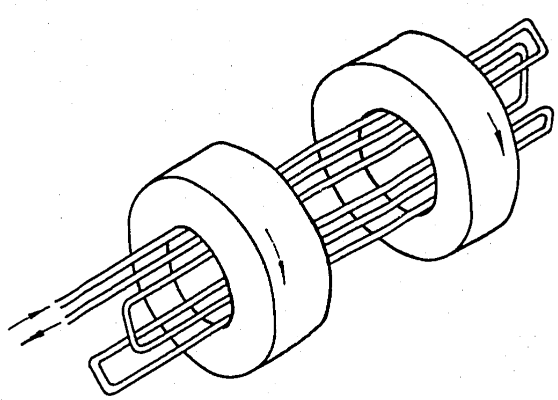

Fig. 3

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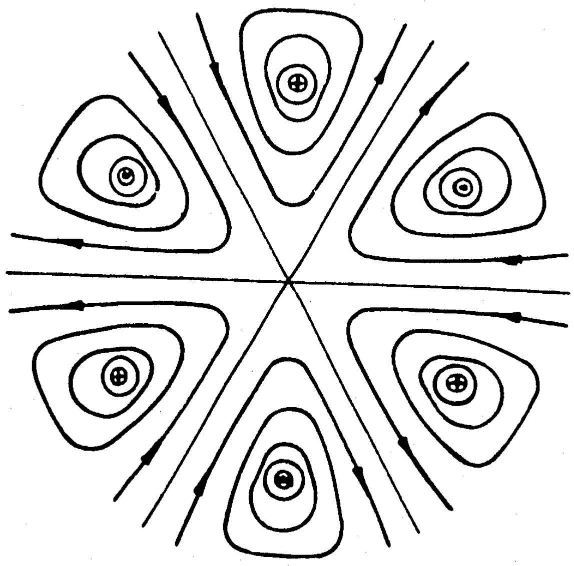

Fig. 4

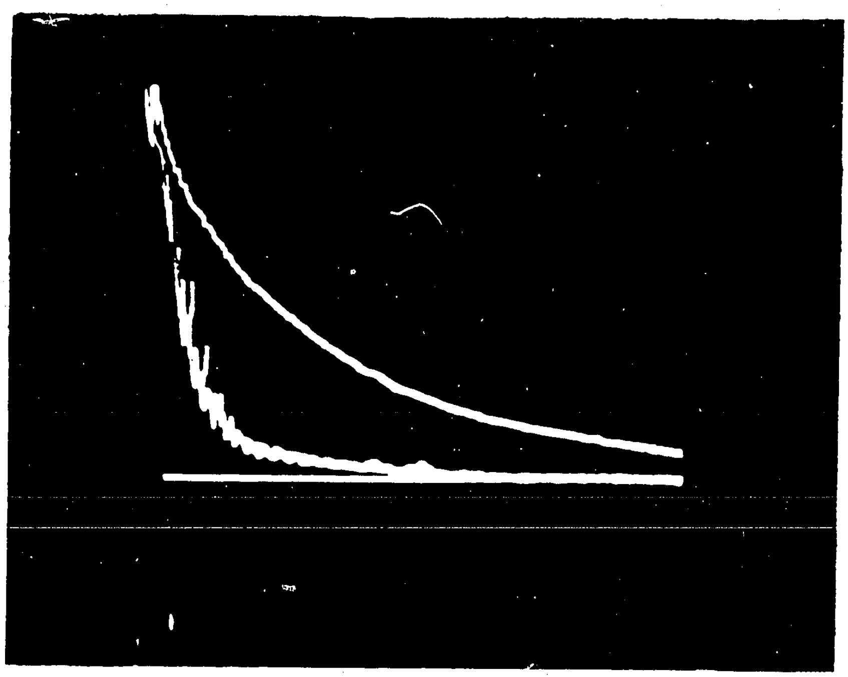

Fig. 5

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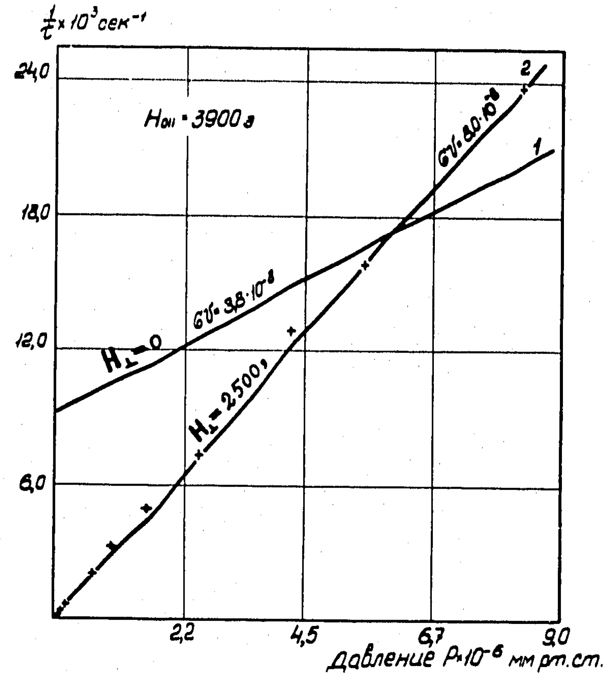

Fig. 6

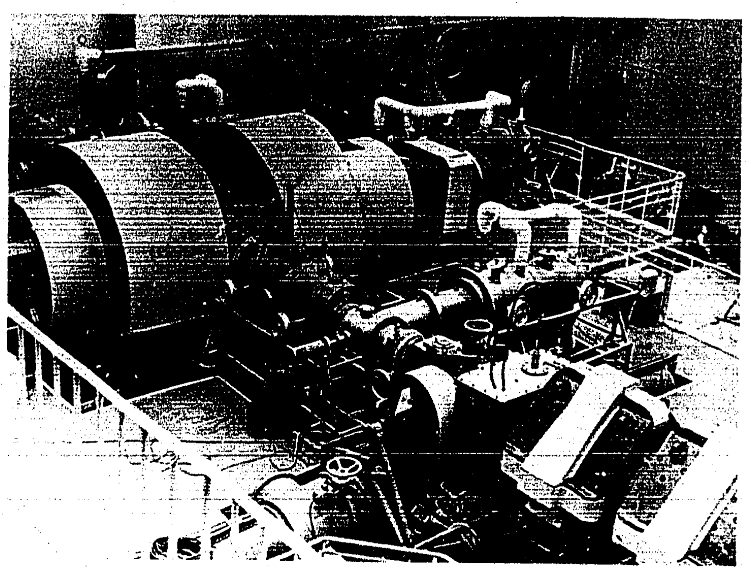

Fig. 7

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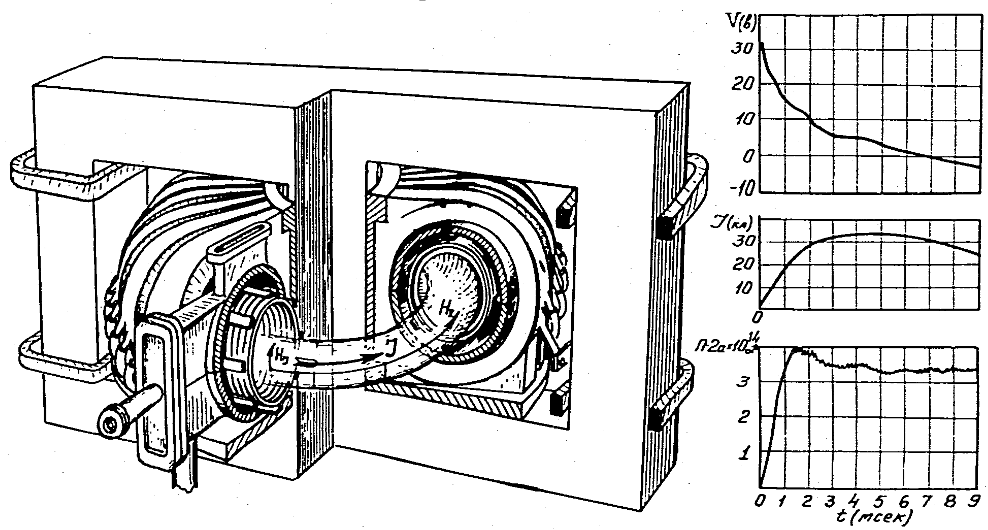
Fig. 8



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